Executive Functions and Access to Language: The Importance of Intersubjectivity

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In *The Oxford Handbook of Deaf Studies in Learning and Cognition.* H. Knoors & M. Marschark (eds).
Funding: MWGD acknowledges support from the National Science Foundation (BCS 1550988). GM's work was funded by the ESRC Deafness Cognition and Language Research Centre (DCAL) Grant RES 620-28-0002.

Abstract

Many deaf and hard-of-hearing (DHH) children who acquire a natural sign language from Deaf parents develop typical executive function skills, and are able to successfully sustain attention, monitor and plan behavior, and avoid distraction. However, for the 90-95% of DHH children born into hearing non-signing families the picture is different. There is now clear evidence that these children are at risk for delayed executive function development and thereby weaker academic performance. This chapter reviews what is known about the development of executive functions in DHH children and its relationship with language development. This is important in light of competing theoretical accounts which attribute executive function deficits to either auditory or linguistic deprivation. An account is proposed that takes into consideration the development of intersubjectivity – the ability of an infant to engage in shared and reciprocal exchanges with caregivers. It is argued that the focus should be on early detection and interventions during the first 18 months that promote successful communicative interactions regardless of modality of language.

Keywords: executive functions, DHH, deaf, language development, intersubjectivity

Executive Functions and Access to Language: The Importance of Intersubjectivity

The development of children’s language facilitates an understanding of others, as well as enabling children to express increasingly complex ideas. Language is a crucial ability for all children as it guides their higher cognition, aiding them to think, remember and plan. As such, language development represents a vital component in children’s success in social and academic settings. How children acquire language is a complex problem but we can agree that children require exposure in sufficient quantity and quality to language to be able to apply any biases they have, as well as development across time in order to gradually construct a lexicon. However, before children use their first words or signs they need to experience interaction in a social setting (Tomasello, 2008). This last part which deals with how children learn to be communicators we think is important for linked cognitive developments.

Language development happens because adults want to communicate with their young child and this can begin almost before the child is born. In these first interactions the learning of a language code is not the primary aim of the encounter but instead adults appear to be more motivated to establish an emotional and psychological link with the child which will foster intersubjectivity. Intersubjectivity refers to the sharing of ideas between individuals (Bruner, 1983; Trevarthen & Hubley, 1978) and the establishment of meaningful interactive and reciprocal exchanges between individuals (Crossley, 1996). This sharing process begins very early in children’s development from neonatal imitation to the development of reciprocation starting at 2 months of age. After this, infants go beyond mirroring others to displaying their first reciprocation in face-to-face exchanges (primary intersubjectivity). By 9 months, typically developing infants engage in triadic intentional communication with others about objects (secondary intersubjectivity) and eventually at 20 months begin to negotiate with others about things and the self as shared representations (tertiary intersubjectivity). In a more recent account of this process, Csibra (2010) provides evidence for how infants seem to be predisposed to detect communicative signals as intentions. These signals are gaze alterations, contingent talk, and parental responsiveness during interaction. Later we will discuss an alternative account of intersubjectivity that has been successfully applied to the specific situation of DHH infants (Loots & Devisé, 2003).

During the first year of life some of the first interactions we have with infants are through turn-taking games and are based on the reciprocal activity of ‘I do something then you respond to it’ (Stern & Gibbon, 1979). Infants and their caregivers co-construct a shared communication using gaze, vocalizations, and gestures, and this sharing of understanding forms the basis of joint attention, future communication, and then language learning (Tomasello, 1988). Successful communication therefore leads on to language development. Of course, communication is not the whole story, from very early on children are also building up the phonotactic properties of their target language(s) and will use these ‘signal’ characteristics to guide segmentation of the language stream (Lany & Safran, 2013). The child’s growth of knowledge in terms of labels for objects and concepts is vital as it facilitates a shared communication about these things between adults and other children and this provides the foundation for doing higher-level cognition, for example thinking about others or planning a sequence of actions. In summary language development produces an appreciation of intersubjectivity as well as a language code and with these two developments a child is endowed with two powerful tools for grasping higher cognitive functions.

We now move on to discuss the potential implications of deafness and early disruptions with communication for wider cognitive abilities.

<1>The Impact of Deafness on Language Development

The DHH children whom Speech and Language Therapists, Educational Psychologists and teachers encounter most often in clinical settings are the 90-95% of the population who are born to typically hearing parents (DCHP: Mitchell & Karchmer, 2004). These parents have to make many important decisions in the first few months after the birth of their children and one of the most important is to follow the route of their child receiving a Cochlear Implant (CI). Spoken language development in DHH children is greatly facilitated by Cis and as the age of the CI decreases the outcomes for spoken language development in this group is improving (e.g. Niparko, Tobey, Thal, Eisenberg, Wang, Quittner et al., 2010). While CIs work very well in terms of improving the acquisition of spoken language for many DHH children, the same is not true for all DHH children. A common but true expression is that CIs do not change a DHH child into a hearing one. Across many studies of spoken language development a recurring finding is the great individual differences and variability (Geers, Nicholas, Tobey & Davidson, 2016; Niparko et al., 2010; Pisoni, Cleary, Geers & Tobey, 1999). Currently much attention is directed at understanding reasons for this variability (Pisoni, Kronenberger, Harris & Moberly, 2018)

In many countries in the Northern Hemisphere families with DHH children begin to explore the option of a CI very early after a neonatal diagnosis of deafness. At present, the age of implantation is decreasing and in some countries is being implemented in the first 12 months. However, even when the CI is implanted early, there continues to be a period of several months before the CI becomes fully operational and speech and language therapy starts to have an impact on the child’s growing linguistic ability. This early period of restricted quality interaction and oral language input means there is often a delay in the onset of spoken language development. But in many cases the gap between a diagnosis and implantation can be considerable e.g. 24 months and in some cases as late as 36 months or more. Before the CI, DHH children will be fitted with hearing aids and so receive some sound stimulation but any disruptions to natural parent-child interaction because of deafness happen just at the most crucial time for the future development of language. (See Levine Strother-Garcia, Golinkoff & Hirsh-Pasek, 2016, for an overview of why the first year is important for language development and age of CI). A less obvious effect of this early period of waiting for a CI is for the establishment of communication through interaction and the development of intersubjectivity.

Deaf parents wo are fluent in assigned language can offer a natural language model that is more accessible (in the beginning of life) to a DHH child. Around 5-10% of DHH children are born of deaf parents (DCDPs) and research has described their acquisition of sign language as resembling that of typically-developing hearing children with respect to the onset, rate, and pattern of early language development (Morgan & Woll, 2002; Schick, Marschark & Spencer, 2005). However again we want to emphasize that the signs themselves are not the most important aspect of this situation initially. Instead deaf parents will have extensive experience of how to communicate with a DHH child. Even though this might be their first child they will have personal experience of growing up being deaf, probably with hearing parents. In addition deaf parents have an awareness of the demands of visual attention, timing and the importance of making any intention accessible, thus visible, to a child. Patterns of interaction in signing will be very similar to those they are aware of when they communicate with other deaf people. As mentioned previously, 90-95% of DHH children are born to hearing parents who have neither previous experience of what deafness means in a family nor the skills to communicate with a deaf person in ways that can compensate for the barrier of deafness. Some DCHP need sign language input if they are to have any access to natural language, for example if the child has a non-functional auditory nerve and is therefore unable to receive a CI. But also it is not clear from the outset which children will become proficient in spoken language or require input from sign to make this progress. Currently there is a lack of pre-implant predictors of outcomes (Pisoni, et al, 2018). In other cases, hearing parents may elect to pursue a bilingual approach incorporating a natural sign language, instead of or in addition to cochlear implantation. This sign exposure for DCHPs typically comes from their hearing parents, although in some parts of the world there are programs where sign-based interventions are delivered by DHH adults (e.g. the Colorado Home Intervention Program) but these types of interventions are increasingly rare. We return to this topic at the end of the chapter.

Learning any second language as an adult can be difficult, this often means that DCHP are first exposed to a version of sign language that is heavily influenced by the parent's first language, reduced in complexity and non-fluent. This non-native input might also appear beyond the first few years of development (Lu, Jones & Morgan, 2016) and, in some cases, considerably later (Morford, 2002). Thus, for the DCHP who uses a sign language for communication, there is potential conflict between the necessary fluent models that may be required for full acquisition of the language and the signing skills of their parents.

Some past research has suggested that fully fluent sign models are not required for successful and complete sign language acquisition. Singleton and Newport (2004) looked at how a DCDP used ASL morphology compared with parents who themselves had only acquired ASL at age 15 years. The child had more developed ASL morphology than his deaf parents which suggests a child can acquire more complex grammatical constructions than those available in impoverished parental input and the authors suggest this could be akin to a creolization process. But, these parents were deaf and had been immersed in ASL for several years before signing to their child. We know very little about how the quality of sign input from hearing parents impacts young DHH children's sign development (Lu et al., 2016). Furthermore, if we accept that early language development is involved in the development of wider cognitive skills, we know even less about how signing from hearing parents can scaffold full cognitive development.

Hearing children do not learn language solely from their parents of course. There is a myriad of inputs from friends, family and the wider world. In contrast, if DCHP are exposed to sign at home, it comes from a small number of people (perhaps only the mother) and so they will inevitably have reduced incidental learning from exposure to language around them (Hall, Smith, Sutter, DeWindt & Dye, 2018). Access to overheard conversations, especially those between older children and parents on topics of misunderstandings or strategic thinking are important sources of information that hearing children automatically assimilate (see Hoff, 2006, for a review). Recently we are learning more about the limitations of CIs in enabling DHH children to overhear language not directed at them (Hall et al., 2018). The DHH child has some disadvantages for overhearing, as currently CIs do not produce clearly distinguishable language signals when there are several mixed speakers, beyond a few meters distance and also in a visually inaccessible area (i.e. overhearing your parents talking to friends in the next room while you are in your bedroom playing on a computer). Finally, there might be a difference between communicating with your parents in their first language versus a new language for them. A first language can possibly afford more intimacy and richer communication (Liben, 1978; Schlesinger, 1978). Thus, hearing parents trying to use sign are going to have additional difficulties in not knowing how to adapt their sign for a baby, will not have experience of using signs with children of different ages nor have knowledge of how babies or young children sign before they develop motoric control (Erting, Prezioso & O'Grady- Hynes, 1990).

At the outset of this chapter, a framework for understanding language development as the result of social interaction was described and possible disruptions because of deafness were outlined. In sum, research suggests DHH children exposed to a signed language from their deaf parents have good joint attention and interaction which sets up a typical awareness of intersubjectivity and no delays in language development. Deafness for DCHP, however, affects the naturalness of early social interaction and attainment of intersubjectivity with their hearing/speaking parents. The consequences of this are often developmental delays in vocabulary and grammar across both language modalities (speech and sign). Next, we discuss the implications of this variability in early social-interaction and language development for development of executive functions.

<1>Language and the Development of Executive Functions

An important area of cognitive development with links to early experience of language and interaction is executive function (EF). EF refers to a set of cognitive abilities, which enable us to coordinate mental processes and manipulate information, solve novel problems, sequence information, and generate new strategies to accomplish goals in a flexible way (Elliott, 2003; Funahashi, 2001). The association of EF and language is one that is currently of fast-growing interest to researchers and clinicians in hearing children with typical (Carlson, Davis & Leach, 2005) and atypical development (Archibald & Gathercole, 2006; Bishop, 2006; Conti-Ramsden, Ullman & Lum, 2015; Duinmeijer, de Jong & Scheper, 2012; Henry, Messer & Nash, 2012; Im-Bolter, Johnson & Pascual-Leone, 2006; Marton & Schwartz, 2003; Montgomery, Magimairaj & Finney, 2010).

There has also been a growing number of studies on this topic in DHH children (Botting, Jones, Marshall, Denmark, Atkinson & Morgan, 2017; Dye, 2014; Dye & Hauser, 2014;

Figueras, Edwards & Langdon, 2008; Jones, Marshall, Botting, St Clair, Atkinson & Morgan, in press; Kronenberger, Colson, Henning & Pisoni, 2014; Pisoni, Conway, Kronenberger, Henning & Anaya, 2010; Pisoni, Kronenberger, Roman & Geers, 2011; Vissers & Hermans, 2018). A broad-brush picture of this literature suggests DHH children perform significantly poorer on all EF tasks than their hearing peers but there is a lot of variability across children and sub-components of EF (see Hall, Eigsti, Bortfeld & Lillo-Martin, 2017a).

To illustrate this in one study, Botting et al. (2017) administered a battery of nonverbal EF tasks to a group of 108 DHH children between 5 and 12 years old and a group of 125 hearing children, matched on age, gender, and socioeconomic status. They found that, on average, DHH children performed significantly worse in comparison to hearing children on inhibition, visual-spatial working memory and cognitive flexibility. Thirteen percent of the DHH children scored more than two standard deviations below the hearing children's average scores on the inhibition task, but only 2% and 10% were at this level on the two visual-spatial working memory tasks, and 12% performed at this level on the cognitive flexibility task (useful analysis reported in Vissers & Hermans, 2018, as Botting et al, 2017 did not look at the data in this way). In a separately published study with the same participants, Marshall et al. (2015) reported that a sub-group of the participants who were DCDP performed at the same level as hearing peers on the two visual-spatial working memory tasks. Thus, across the same children there are differences between different EFs, and different groups of DHH children perform differently across the same EFs. This highlights the importance, when interpreting results across EF studies with DHH children, of looking closely at the sample of DHH children tested and the tasks used (or if results are based on an EF questionnaire). In many cases, such as DCHP with CIs, the quality of access to language and the degree of intersubjectivity experienced by the children is unknown but likely to be highly variable. On the other hand, studies with DCDP are likely to have recruited children with typical language acquisition profiles, and/or children and who might have experienced high levels of intersubjectivity from infancy onwards. Dissociating hearing levels, parental communication mode (sign vs. speech), language choice (a signed vs. a spoken language), use of a CI, and intersubjectivity is a challenging endeavor. These factors are highly correlated and obtaining large enough samples of specific sub-groups – such as DCDP with cochlear implants who are fluent signers – is extremely difficult.

It is also important to note that there have been very few longitudinal studies of EF development in DHH children. Most findings are cross-sectional and therefore correlational in nature. This makes it hard to establish causality or the directionality of any potential causal relationships (with some limited exceptions, e.g. Jones et al., in press, discussed below). Although it is tempting to consider composite measures of EF, it is not clear that these individual functions share a common underlying basis (and this may be different for children versus adults). Here we discuss studies of EF in DHH children by dividing them according to the kind of function tested. Here we consider the EFs that have received the most attention in studies with deaf children: *sustained attention*, *inhibition*, *working memory*, *shifting* and *planning*.

<2>Sustained Attention

The ability to sustain attention over time is a crucial component of flexible, task-oriented behavior. A common measure used to assess a child's ability to stay "on task" and avoid distraction is the continuous performance test (CPT). While many variants of the CPT exist, they share common features. Children are typically required to attend to a long sequence of stimuli that appear one at a time, and make a response to an infrequent target or target sequence. CPT performance in deaf children was initially reported by Quittner, Smith, Osberger, Mitchell and

Katz (1994), who reported that DHH children aged 6-13 years showed poorer sustained attention performance relative to typically hearing peers. Furthermore, their analysis of those DHH children with CIs, while cross-sectional, implied that restoration of hearing might improve sustained attention. The same group replicated this finding using a finer-grained, but still cross-sectional, sample (Smith, Quittner, Osberger & Miyamoto, 1998). Horn, Davis, Pisoni and Miyamoto (2005), who examined CPT performance pre- and post-cochlear implantation in younger children, were the first to report longitudinal data. While that data suggested improved performance post-implantation, the reported effects were very small, and no typically hearing peers were tested. More recently, Dye and Hauser (2014) tested sustained attention using a CPT with DHH children attending residential schools who used American Sign Language (ASL) as a first language acquired in infancy (see also Hall, this volume). Their data showed little-or-no difference in sustained attention between DHH and typically hearing children across the 6-13 year age range. Where Dye and Hauser (2014) did find a difference in performance was on a CPT variant that includes distractor stimuli flanking the target sequence. In the presence of such flankers, performance dropped for both DHH and typically hearing children across the age range tested. However, that drop in performance was significantly greater for younger (6-8 year old) DHH children. They concluded that sustained attention did not vary as a function of hearing level, but that younger DHH children were less able to filter out the influence of task irrelevant flankers. It is not clear whether this reflects an EF deficit or an ecologically adaptive reallocation of visual attention across the visual scene. Ongoing work is investigating whether DHH children’s ability to sustain attention may be bolstered by early exposure to sign language if they are the offspring of a DHH parent. However, the picture is less clear for DHH children with hearing parents who are exposed to poor quality spoken and signed language. While sign is easier to access for these children, as they still find perception of speech sounds challenging, this exposure to sign comes from parents who are themselves beginning to learn the language. It is also not clear if, and indeed how, language input from hearing parents who sign and speak *at the same time* can influence EF skills.

<2>Inhibition

Closely linked to sustained attention is the EF ‘inhibition’ which refers to the child’s resistance to interference. In an early study using the Behavior Rating Inventory of Executive Function parent questionnaire (BRIEF), Hintermair (2013) found that 22% of the DHH children had elevated scores (T-score ≥ 65) on the Inhibition subscale (high scores indicate a particular weakness). The proportion of DHH children with very elevated scores (in the clinical range) was three to five times larger than the number of hearing children with very elevated scores.

Kronenberger et al. (2014) used a parent-reported behavior checklist termed the Learning, Executive, and Attention Functioning Scale (LEAF) with 73 DHH children aged 7-17 years and found significant delays in inhibition (and other EFs) (see also Kronenberger & Pisoni, this volume). Finally, Marschark et al. (2015) carried out a wide-ranging study of EF in DHH and normal hearing college-age students. Hearing individuals performed more strongly than deaf individuals on self-reported measures of inhibition, regardless of sign language skills or use of CIs. This study is important as it suggests that it is both deafness and language-deprivation that many influence EF development.

Looking in more detail at inhibition, Botting et al. (2017) administered a computerized version of the *Simon task* (Simon, 1990). On each trial either a sun or an apple appears on the screen either left or right of center. The children are instructed to respond by pressing a key with a sun sticker on the left-hand side of the keyboard when they see a sun appear, or a pressing a key with an apple sticker on the right-hand side when they see an apple appear. Each stimulus appears for 750ms. The order of trials was randomized for each child and no feedback was given. There was a total of 32 trials, half congruent (picture on the same side as the response) and half incongruent (picture on the opposite side of the response). The increased time to respond to incongruent items is known as the Simon effect (Simon, 1990): an ‘interference score’ was therefore created for the analysis by subtracting congruent from incongruent scores. Results indicated DHH children aged 6-11 years old and from a wide range of language and communication backgrounds, performed more poorly than hearing children as age controls. The DHH children had elevated Inhibition (interference) scores; that is, they found inhibition difficult. All EF scores were transformed into Z scores based on the hearing sample’s mean and SD to allow comparison and to examine how many children scored in an impaired range (1 SD below the mean of the hearing peers). For the Simon task, 44 DHH children (41.5% of the sample) had scores in this -1 SD range and 14 (13.2%) were -2 SD below the hearing mean. None of the DHH sample had been picked up with EF difficulties by educational staff prior to recruitment.

<2>Working Memory

Working memory here refers to the ability to maintain and manipulate mental representations. One way in which such an ability is often measured is using a forward versus backward recall memory task. For example, a child may be asked to recall a sequence of visually presented digits, with the number of digits increasing until the child is no longer able to successfully recall them in the correct order (called a forward digit span). Performance on this task is compared with backwards recall, where the digits must be recalled in reverse order (backward digit span). The additional operation of having to mentally transform the sequence of digits reflects working memory ability. When using ASL to perform such a task, Wilson and Emmorey (1997) have shown that DHH children who are native ASL signers have equivalent forward and backward spans. While spans using ASL stimuli in DHH children are typically smaller than those obtained using spoken English with typically hearing children, Boutla, Supalla, Newport and Bavelier (2004) have demonstrated that, at least in adults, this is driven by language modality rather than hearing status. Pisoni and Cleary (2003) administered the WISC-III forward and backward digit span tasks to a large sample of 8-9 year old CI users and a group of typically hearing age-matched controls. The typically hearing children outperformed the DHH children on both span measures, perhaps not surprising given the auditory-verbal nature of the task. However, the drop in performance from forward to backward recall was smaller in the DHH children than in their typically hearing peers. It is unclear whether this reflects better working memory because of the overall short-term memory differences that were likely attributable to lower hearing levels on the DHH children.

Using longitudinal data and the same WISC-III tests, Harris, Kronenberger, Gao, Hoen, Miyamoto and Pisoni (2013) reported significant variability in DHH CI users when assessing growth in forward and backward recall performance, with forward and backward recall growth seeming to vary independently. This suggests that short-term memory for spoken material may develop independently of the EF-related working memory skills needed to mentally manipulate those speech representations. Of note, while task performance was predictive of performance on subsequent spoken language assessments, the effect was strongest for the subgroup of CI users who showed delayed growth in both forward and backward recall.

In another longitudinal study of EF development in DHH children, Jones et al. (in press) measured non-verbal visuo-spatial working memory with the *Odd One Out Span* task (Henry, 2001). In this task the child has to identify which shape is the odd-one-out and remember its location. When a trial is complete, the location of the odd shapes is recalled by pointing to the correct box in a sequence of empty grids. There are four trials within a block, beginning with one item to recall. Each block of trials increases in the number of shape locations to recall with a maximum of six. The test is terminated when two errors are made within the same block. A score is calculated by totaling the number of correctly recalled shape locations (maximum 36). In addition, the authors used the *Backwards Spatial Span task* (Corsi blocks: Wechsler Nonverbal Scale of Ability; Wechsler & Naglieri, 2006) which is also a test of non-verbal visuo-spatial working memory. The experimenter taps a sequence of blocks and the child is instructed to tap this sequence in reverse. Each trial increases the number sequence to a maximum span of nine. The test is terminated after two errors at the same span length, and scored by tallying the number of correct sequences. Working memory performance was evaluated at two time points (24 months apart). A series of repeated measures ANOVAs revealed significant main effects of Group for the Odd One Out (working memory) and the Backwards Spatial Span tasks (working memory), meaning that the hearing group performed significantly better than the DHH group on executive loaded working memory tasks. There were significant main effects of time for all EF tasks, indicating improved performance between the two testing time points for both DHH and hearing groups overall. None of the group by time interactions for performance on EF tasks were significant, indicating that the amount of improvement of DHH and hearing children did not differ significantly. This last result is encouraging as it indicates that the gap between DHH and typically hearing children did not decrease over 24 months. As described in the following section on' Potential Linking Mechanisms' the one variable which predicted improvements in working memory over time was vocabulary level (whether signed or spoken).

<2>Shifting

Botting et al. (2017) assessed DHH and hearing children with the Children's Color Trails Test 1 and 2 (CCTT) (Llorente, Williams, Satz & D'Elia, 2003) as a test of cognitive flexibility or switching. For test 1, the children are timed drawing a line connecting the numbered circles from 1 to 15. In Test 2, two sets of numbered circles are printed: one set of circles filled with pink, and the other, yellow. Children are required to join the numbers in ascending order, alternating between colors. In this study, an interference score was calculated, showing the 'additional time' taken in Test 2. Analysis of the data revealed the hearing group performed significantly better than the DHH group on the CCTT. In a longitudinal follow up 2 years later, Jones et al. (in press) found that while their language and EF improved DHH children still performed more poorly than hearing peers on the CCTT switching task. This is still the case even though the task has low verbal demands. Switching, as with working memory tasks, was best predicted by language development and may have higher language demands through verbal strategizing (Fernyhough & Fradley, 2005).

<2>Planning

Botting et al. (2017) assessed planning with the *Tower of London (ToL)* task, which is a simplified version of the Tower of Hanoi task (Shallice, 1982) that measures executive planning. Colored disks need to be moved from their initial formation, one by one, to match a target configuration. To score the task, the number of additional moves over the minimum number of possible moves is calculated. A comparison of DHH and hearing children by Botting et al. (2017) revealed fewer differences in planning skills between groups than in other aspects of EF. Furthermore, while language skills were strongly related to EF this was less the case with planning. When Jones et al. (in press) looked at vocabulary at Time 1, it did not predict *change* in planning scores over the two-year period. Data for this final EF – planning – highlights that while language is implicated in EF it may not be to the same degree or for the same reasons across all EFs. For example, the working memory, inhibition and shifting measures might be more associated with early developmental disruptions. However, the planning task (Tower of London) may be more reliant on concurrent implementation of self-talk. In the wider literature (e.g. Miyake et al., 2000) planning is a higher order EF underpinned by the other factors. As such, it might be the case that planning is less influenced by the developmental experience of good interpersonal interaction as the main EF factors covered so far (e.g., Lidstone, Meins & Fernyhough, 2011). We now turn to the issue of the impact of early experiences of interpersonal communication on EF in more detail.

<1>Executive Functions and Language: Potential Linking Mechanisms

There are several possible theoretical explanations for a developmental link between language skills and EF. While EF and language might be interrelated, it has been difficult to untangle the direction of influence from previous research (e.g., Fuhs & Day, 2011; Kuhn, Willoughby Wilbourn, Vernon-Feagans, Blair & Family Life Project Key Investigators, 2014). For example, language skills may enhance EF because rules derived from learning language enable children to better plan and monitor their behavior via the ability to use vocabulary as labels to create internal representations. This is described in the Cognitive Complexity and Control (CCC) theory put forward by Zelazo and Frye (1998). The CCC argues that rules derived from language learning enable manipulation of cognitive processes via internal representations. Good vocabulary enables children to automatically process information via integrated language representations thus freeing up cognitive load to engage in meta-cognitive strategies. During several higher-level cognitive tasks, such as those requiring EF, it is evident that children and adults use these meta-cognitive strategies, that is, self-talk, to assist them, even in in situations where the task is non-verbal in nature (Duncan & Cheyne, 2001; Fernyhough & Fradley, 2005). In the few existing longitudinal studies, early language appears to predict later self-regulation skills and EF in typically developing children (Kuhn et al., 2014; Petersen, Bates & Staples, 2015; Jones et al., in press) more than the other way around.

However, it is also plausible that EF might support language acquisition, which includes vocabulary, by helping children to pay attention, deal with several sources of information at the same time, keep track of their mistakes, and synthesize information in order to make decisions (Diamond, 2013; Weiland, Barata & Yoshikawa, 2014). The relationship may of course be reciprocal, and language and EF may influence one another in simple or complex ways across development (Bohlmann, Maier & Palacios, 2015). For example, certain EFs may be more influential in the early period of development during the onset of language while this relationship flips over in older children where language might push the more advanced use of higher EFs (Bishop, Nation and Patterson, 2014). Thus, there are various possible linkages between language and EF, but typically developing children often have few disparities between their expected language and EF skills that would permit researchers to look for predicted effects of one on the other. The advantage of studying DHH individuals in this domain is that the language deficits seen in DCHP typically reflect delayed rather than disordered functioning as in autism spectrum disorder (see Boucher, 2011 for a review). An added complexity is linked to the problem that several cognitive abilities are grouped together under the term EF. Because EFs are a set of arguably dissociable abilities, it is also plausible that different EF skills may follow independent developmental pathways, some of which may be more strongly associated with language (and thus more affected by the consequences of deafness) than others. Indeed, this seems to be the case after looking across a range of studies and different EFs.

<2>Scaffolding at Different Levels

Language and cognitive development appear to be ‘typical’ in DCDP, which should provoke researchers and educators to think about what aspects of having a deaf parent are most protective. There will be many things that this environment offers DHH children: early exposure to language, natural and fluent interaction, and increased sense of acceptance to name but a few. There are also likely to be differences in the etiology of hearing loss (Dye, Hauser & Bavelier, 2008), age of suspicion (or assumption) of hearing loss (Störbeck & Young, 2016), and in other parental factors such as stress and acceptance (Lederberg & Golbach, 2002; Quittner et al., 2010; Zaidman-Zait, Most, Tarrasch, Haddad-eid & Brand, 2016). Some of the DCDP advantages will be shared with hearing children with hearing parents and others might be unique to being in a deaf family. But, as Marschark et al. (2015) point out, a major objective of research into deafness is understanding relations between language use and cognitive abilities among DHH individuals who are more representative of the larger deaf population than the 5-10% who have deaf parents. The population of DHH children where our work is most relevant is the 90-95% of infants who have two hearing parents.

As described in the previous sections, DHH children with hearing parents generally have limited auditory and sign language input during first 12-18 months of life. In addition, spoken language input improves post-implantation, but it can take months or years for these children to catch up with their ‘hearing-age’ peers. Hearing-age refers to the duration of life with the CI rather than the chronological-age of the child. Levine et al. (2016) propose three main areas of development that appear to be at risk in the first stage of life when a DHH child is born (see also Levine, Guerrero, Golinkoff, Hirsh-Pasek, & Houston, this volume):

(1) Potentially reduced communication foundation with primary caregivers.

(2) Increased sensitivity to the variability of their language environment compared with typically developing children. The quality of the home environment might be more important for CI children.

(3) Differences in experience-based domain-general cognitive alterations (i.e. selective attention and sequencing skills).

Linked to the third point, one theoretical perspective outlined by a group of researchers working in the area of deaf cognition was based on the notion that speech perception/exposure through an intact auditory system was the crucial factor in predicting EF. From this work the Auditory Scaffolding Hypothesis emerged (Conway, Pisoni & Kronenberger, 2009; see also Kronenberger & Pisoni, this volume; Hall, this volume). Briefly stated, this hypothesis proposes that EF, and other important neurocognitive abilities, emerges from an interplay between audition and spoken language development. It is argued that the auditory system is better able than the visual system to process sequential information and create temporally distinct representations. In turn, this supports the acquisition of spoken languages that have hierarchical structure that is crucially depended upon sequential-temporal representation, and the emergence of cognitive abilities that are temporally-dependent – working memory, sequencing, and sustaining attention over time. A similar proposal was put forward by Kral, Kronenberger, Pisoni and O'Donoghue (2016), who argued that congenital deafness should be conceived of as a "connectome disease" whereby the decoupling of auditory brain regions from association cortex leads to neurocognitive disorders.

However, the inclusion of DCDP in EF studies has revealed that this group, at least, displays age-appropriate EFs within the domain of sustained attention and working memory (Dye & Hauser, 2014; Marshall et al., 2015). DCDP also do not evidence impairments on implicit sequence learning tasks (Conway, Karpicke, Anaya, Henning, Kronenberger & Pisoni, 2011; Hall et al., 2017b; Hall, this volume). Typical development of EFs again appears conditional on the child having had an early experience of language and communication that is effortless and engaging, such as is likely to be the case for DCDP.

In summary, having deaf parents may well protect the young DHH child from EF delays, although there is wide variation between deaf parents, it is the case that in general, they can offer early and good access to language. However this is an exception for DHH children (90-95% of DHH children have hearing parents). Theoretically, it is possible that EF will develop normally if hearing parents could communicate with a sufficient level of sign language proficiency. However, in the real world this is not straightforward, and, for a section of the young DHH population with CIs, spoken language communication is also difficult to establish. EF delays therefore need to be studied and explained within the wider DCHP population.

It is possible that DCHP who are exposed to degraded sound-based language and poor levels of signing have difficulties with scaffolding of cognition, although the performance of DCDP suggests that the auditory system is an unlikely mechanism. Without the protective factors of good early interactions these difficulties could persist into later childhood in the absence of effective interventions. It is not clear at this time how much language (signed/spoken or both together) is enough to facilitate the development of a functioning EF system. In any event, the Auditory Scaffolding Hypothesis as an approach to understanding the cognitive development of DHH children may not be discarded at this point, although its underlying mechanism and scope has been brought into question.

In contrast to the Auditory Scaffolding Hypothesis is the Language Scaffolding Hypothesis, which argues poor EF in DHH children is the consequence of language learning being disrupted (see Hall, this volume). The argument would be that language development facilitates EF performance. However, research exploring language and EF in DHH children has revealed mixed results. Remine, Care and Brown (2008) found no association between language and EF, while Figueras et al. (2008), who included a relatively large sample of DHH children (n = 47), found that both EF and language scores were lower in the DHH group, and that the two domains were highly associated. In two recent studies, (Botting et al., 2017; Jones et al., in press) language was shown to mediate group differences in EF skill, but the reverse pattern was not evident. At follow-up, two years later, all children improved their scores on all tasks over this period, but DHH children performed significantly less well than hearing peers on some EF tasks and a vocabulary test. Regression models showed that vocabulary at Time 1 predicted change in EF scores for both DHH and hearing children, but not the reverse (Jones et al., in press). Thus, we conclude from this work that even though DHH children were making impressive gains in terms of spoken language development (possibly as a result of early identification of deafness, widespread inclusion in mainstream schooling and increased speech perception), language development delay was still an issue. This meant that language and EF were poorer in DHH children than in their hearing peers and we argued that these two factors were related.

But language is a product of early interaction and communication. In this chapter, we have focused on communication with caregivers as a precursor to language and EF development.

We proposed that early social-interaction promotes language and EF development. In Figure 1 we show this relationship between social-interaction, intersubjectivity, language and EF.

INSERT FIGURE 1 ABOUT HERE

Within our model there are two reasons for the language-EF relationship: one is developmental and the other concerns how children use language while carrying out the EF tasks. We expand on these two explanations next.

<2>The Intersubjectivity Scaffolding Hypothesis

The intriguing position we propose is that both EF and language grow out of early communicative interactions that children experience in the first years of life, and that this relationship is developmentally vulnerable – the *intersubjectivity hypothesis*. Importantly, this model differs from that proposed by Visser and Hermans (2018) for whom the chief factor behind EF delays in DHH children is a lack of private speech. Under our approach, early parent-child interaction and the development of *intersubjectivity* is crucial not only for the development of good language skills (Akhtar, Dunham & Dunham, 1991; Cartmill, Armstrong, Gleitman, Goldin-Meadow, Medina & Trueswell, 2013), but also for the development of EF skills – especially emotional and cognitive regulation (Hughes, White & Ensor, 2014; Lowe et al., 2012). In the typical scenario, infants will have full access to the rich interactions offered by caregivers' scaffolding of communication (Hughes et al., 2014). Hearing children, and probably DCDP, will be surrounded by adults who use language to regulate and foster self-regulation in the same children. In contrast, communication between hearing parents and a DHH infant is much less effective (Harris, 2010; Wedell-Monnig & Lumley, 1980). For example, mothers of CI-implanted children reduce the communicative demand (e.g., less use of open-ended questions; DesJardin & Eisenberg, 2007) and use less syntactically complex utterances (Moeller &

Tomblin, 2015). Fagan, Bergeson and Morris (2014) found that, just like many parents of infants with a ‘disability’, mothers of children with CIs use more directives (e.g. “say” ‘cat’, “sit here”) and prohibitions (e.g. “no”, “don’t open it”) than mothers of age-matched hearing children. Thus, as a group DHH children experience a reduced and less demanding communication interaction with primary caregivers (Levine et al, 2016). While this experience undoubtedly contributes to a delay in language development, we propose that it also impacts the development of early EF abilities as it offers far fewer opportunities for self-planning, inhibition and control of interactions by DHH children. In wider research on hearing infants it is suggested that parents who stimulate their children to be more active in learning about their environment while positively scaffolding their children’s actions with contingent language show most EF benefits (e.g. Devine, Bignardi & Hughes, 2016). Stemming from this work our proposal here is in line with the work of Roos, Cramér-Wolrath and Falkman (2016) who have shown that deaf parents are able to appropriately scaffold the development of intersubjectivity in their deaf infants during the first 18 months of life. Roos et al. (2016) studied twelve such infants using the framework proposed by Loots and Devisé (2003). Briefly, this framework proposes that children pass through a series of stages as they develop meaningful interactions with their caregivers. At birth, the infant synchronizes their behavior with that of the mother – as the mother nods her head, the infant may open-and-close her mouth with a similar rate and timing (*emerging* subjectivity). Around 2-3 months, this gives way to *physical* intersubjectivity, where repetitive interactions between a mother and child occur, such as those evidenced in games like *Peek-a-boo*. Towards the end of the first year of life, intentions and emotions come into play, with mother and child establishing shared understandings (*existential* intersubjectivity). Finally, early in the first year of life, the *symbolic* intersubjectivity stage occurs, involving interactions that exchange linguistic and other symbolic forms of meaning. Loots and Devise (2003) discuss several scenarios where successful progress through these developmental stages may be at risk for DCHP. For example, they suggest that repetitive vocalizations are unlikely to elicit synchronized responses from deaf newborns – a risk to emerging and physical subjectivity (but see Sanford Koester, Brooks & Karkowski, 1998); hearing mothers are less likely to use affective facial expressions or modulate visual language appropriately to express emotional state (Reilly & Bellugi, 1996) – a risk to existential intersubjectivity; and they are also less able to appropriately direct a young child's attention or establish joint attention (Depowski, Abaya, Oghalai & Bortfeld, 2015) – a risk to symbolic intersubjectivity. Roos et al. (2016) observed that deaf mothers circumvent these risks via visual-tactile ways of communicating and directing attention, resulting in typical intersubjectivity development during the first 18 months of life for their deaf infants. Importantly, parents who used a combination of signs and speech with their DHH infant seem to develop typical emerging, physical and existential intersubjectivity (Loots, Devisé & Jacquet, 2005). However, age-appropriate symbolic intersubjectivity – crucial for the transition to symbolic language development – was only observed in families using a sign language (Loots et al., 2005).

A failure to fully achieve symbolic intersubjectivity leads to a delay in vocabulary development and a subsequent difficulty with aspects of EF. Cognitive Complexity and Control (CCC) theory (Doebel & Zelazo, 2016; Zelazo & Frye, 1998) maintains that good vocabulary enables children to automatically process information via integrated language representations thus freeing up cognitive load to engage in meta-cognitive strategies. During cognitive tasks such as those requiring EF, children and adults are able to employ meta-cognitive strategies such as private speech even in in situations where the task is non-verbal in nature (Duncan & Cheyne, 2001; Fernyhough & Fradley, 2005). Fernyhough & Fradley (2005) describe that before 5 years private speech is explicit and then becomes internalized by 7 years. As a task gets harder, private speech becomes more externalized. Lidstone, Meins and Fernyhough (2012) found that 7-11 year old hearing children with language impairments used less optimal private speech, which they argued was a limiting factor on an EF task. Better language development in DHH children would also mean a more fully developed use of private speech or sign and conversely a language-delayed DHH child is less likely to be able to exploit private speech in order to free up cognitive load, so as to engage in meta-cognitive strategies (see a recent parallel explanation for EF difficulty in DHH children from Vissers & Hermans, 2018).

As EF involves the control of behaviors via accessing these previous language-mediated experiences, DHH children who have poorer integration of language representations are also likely to be at a disadvantage. DHH children will experience more cognitive load in EF tasks and might not engage in good meta-cognitive strategies. Thus, on both counts children with delayed language development resulting from their deafness will experience difficulties in both the establishment of early EF skills, where self-regulating speech is linked to early experiences of interaction with an adult which the child first models and internalizes (Fernyhough & Fradley, 2005). This can be seen in the later implementation of those EF skills when language resources are needed to boost EFs through self-talk.

It is an empirical question as to whether DHH children with poor language development also might have less sophisticated private speech or private sign. Vygotsky (1962) argued that private speech grows from early social-interaction, and is then modelled by the child in private. In this light, DCHP's poorer early social interaction and ensuing difficulties with language development might reduce the development of private speech during problem solving tasks. It is also possible that a DHH child who signs ‘out-loud’ will find it more difficult to implement private speech while manipulating objects, for example in an EF task such as the Tower of London.

<1>General Conclusions

The case of DHH children emphasizes how early interaction is crucial for language development and related cognitive abilities. DCDP are more likely as typically hearing children to have good early language and cognitive development for a variety of reasons: shared language with parents, barrier-free social interactions, parents who are familiar and experienced in effectively communicating with a deaf child, and a strong sense of identity, although we know very little about how even DCDP are susceptible to the various factors that lead to variable outcomes in hearing children (differences in parents’ input, socio-economic status and/or education level). DCHP would benefit from this richer linguistic environment, but the question is how can those effective strategies used by deaf parents be made feasible and accessible to hearing parents? There is a pressing need to create and systematically evaluate early interventions aimed at increasing communication abilities that have a positive consequence for language skills. If language development can be achieved via excellent communication, research suggests this will foster age-appropriate cognitive abilities. However, the key problem is that it remains a challenge for DCHP to experience early access to communication through sufficiently proficient sign language communication with their hearing parents.

At the same time, we still observe gaps in DHH children’s spoken language development, because hearing parents both reduce the quality of their early interactions, and much of what hearing parents talk about between themselves (incidental conversations) is not accessible to DHH children until several months later once they have received a CI. The questions for the future are practical ones. Will CIs become functional earlier and give better access to spoken language communication leading to better interactions? Alternatively, will the sign language skills of hearing parents improve to meet the needs of their young DHH infants? Should professionals working with families of DHH children put their efforts into improving the sign language of parents or providing better and earlier spoken language interventions? It is probably the case that both types of support are needed: early speech/sign language and communication interventions to develop interaction and intersubjectivity, followed by a CI and spoken language therapy to develop access to the surrounding and pervasive spoken language and print world.

<1>Implications for the Classroom

If social-interaction and the Intersubjectivity/Language Scaffolding Model represent a ‘mechanistic’ explanation for how access to language supports EF development, it might follow that interventions should be based on an attempt to create optimal early social-interaction. There should be more work in the future that not only demonstrates differences in performance between DHH and hearing groups but also on how we could *prevent* and/or *remediate* language and EF delays. In the past, there have been such interventions proposed based both on hearing parents using spoken language, signed languages, or both. Evaluation of programs designed to provide rich sign language input to DCHP, for example the Colorado Home Intervention Program (CHIP) in the USA and Family Sign Language Courses run by the National Deaf Children's Society in the UK, is sorely needed.

Here we suggest a move away from training families in a specific language and instead refer to language/early communication skills of parents. Indeed, sticking to one language for hearing parents is difficult during the early months when they start to sign, and most parents will sign and speak to their children at the same time. This mixing of sign and speech, for example sign supported English, will change constantly in its closeness to sign or speech along a spectrum. Mixing will also differ depending on the abilities of the child to speak, the sign skills of the hearing caregiver, and the domain of knowledge being expressed (i.e. it may be easy to sign a conversation about animals, but more difficult to sign conversation about strategies for not getting angry when frustrated). The findings from Loots et al. (2005) suggest that, for parents who choose a bilingual approach incorporating a signed language, there remains the possibility of transitioning from a combination of speech and signs towards natural signed communication as the parents develop increasing linguistic competence during the first 18months of their DHH child's life. As long as the combination of speech and sign facilitates successful development of intersubjectivity, the foundations of successful communication and subsequent EF development may be in place.

Thus, our Intersubjectivity/Language Scaffolding Model does not dictate how social-interaction should occur but rather that it should be embedded in the language or languages that are the most effortless for parent and child to establish and communicate with. The field of deafness and language/cognitive development is dominated by the circular question of whether hearing parents should or should not use sign language. Within our model, these parents can use sign in conjunction with all other ways of communicating. It may be the case that having to sign distracts parents from what could otherwise be a good communicative interaction be it through speech, gesture or any other medium. The powerful role of sign languages, here, is that they can increase the effectiveness of communication and develop healthy intersubjectivity. Furthermore, this might change as the child develops. Rather than focusing on the signs or words themselves, that is the *language*, it is the interaction and contingency which is the focus. The goal is to set up intersubjectivity scaffolding and then language at appropriate times in development.

In terms of how EF relates to learning, much research agrees that EF early in the child's life (at 2 years for example) predicts educational success later in childhood (Blair & Razza, 2007; Bull, Espy & Wiebe, 2008; McClelland, Cameron, Connor, Farris, Jewkes & Morrison, 2007). If DHH children are delyed in areas of communication and language at this time the impact on EF might well be seen in their later academic attainment. We know that EF processes are especially important in novel or demanding situations where children are asked to make quick and flexible adjustments to behavior in changing environments. This context describes a busy mainstream classroom very closely (Huizinga, Baeyens & Burack, 2018).

As a specific task, solving mathematical problems requires good working memory which facilitates the retrieval and storage of partial results and processing of information while it is stored (Cragg & Gilmore, 2014; Dehaene, 1997). A more general influence of EF in the classroom is that it improves behavioral regulation and learning-related behaviors – a child's ability to pay attention to the teacher's instruction (Fitzpatrick and Pagani, 2012; Gathercole, 2004). A DHH child who finds it difficult to both complete a task and listen to the ongoing discussion of what task is required next, might not make the most of her learning potential (Alexander, Entwisle & Dauber, 1993; Duncan et al., 2007; Howse, Lange, Farran & Boyles, 2003).

We are not born with fully functional EFs: these skills begin to develop in infancy and continue into early adulthood. However, a person's EF skills are not fixed, but can be improved or "trained". EF skills are this malleable and can be enhanced by different experiences (Diamond & Lee, 2013; Diamond & Ling, 2016; Sasser, Bierman, Heinrichs & Nix, 2017). There is currently a great interest in developing and evaluating the effects of EF training. In our model EF skills are the product of both early successful interaction as well as good language skills. EF interventions may well link in with the second scaffolding mechanism. Having good language enables children to use verbal strategies to perform better on EF tasks. One such intervention (Zelazo, Forston, Masten & Carlson, 2018) incorporated self-reflection training in the classroom. In their Iterative Reprocessing Model (e.g. Cunningham, Zelazo, Packer & Van Bavel, 2007; Zelazo, 2015) a set of meta-cogntive strategies were trained including noticing challenges, pausing, considering the options, putting things into context prior to responding, and monitoring progress toward a goal. Several of these strategies will involve self-talk.

To our knowledge, there have been no published studies of EF training for DHH children. The only exception to this is a recent study (Mason, Marshall & Morgan, in press) which looked at the impact of a music-based intervention on DHH children's EF skills. DHH children all with typically hearing parents aged 7-11 years old and from three different schools received 10 hours of music-based EF training and 10 hours of art classes (which acted as a control condition). The music-based EF sessions were designed specifically for DHH, and included fun and engaging activities, which aimed to challenge and train their attention, inhibition, memory and planning skills while engaging in musical games. The study found that the musical training and games had a positive effect on the children's memory and inhibition skills, highlighting the importance of music classes and their potential benefit to DHH children's cognitive development.

<1>Future Areas for Investigation

Throughout this chapter we have the emphasized the importance of looking beyond language itself. We proposed that EF deficits in DHH children are better understood within the context of an Intersubjectivity/Language Scaffolding Model. Our contention is that it is the early communicative interactions with parents that are critical for the successful development of both language and EFs. These interactions are driven not by the goal of acquiring a language, but by the need to communicate needs and intentions, and to share affection and love and thereby develop a strong caregiver-infant bond. To the extent that cochlear implantation and the acquisition of spoken language permits this for a DHH child within a sensitive period in development, that approach is likely to foster good EF abilities in the child. Likewise, if hearing parents are able to acquire a sign language fast enough and with sufficient proficiency, then this too stands to promote healthy cognitive development. However, for most families with a DHH child, one or the other approach is unlikely to be attempted – or successful – on its own. More research on early multimodal communicative interactions between DHH children and their caregivers (e.g. Roberts & Hampton, 2018) is urgently needed.

We also need rigorous evaluation of programs such as CHIP and the Family Sign Language Courses offered in the USA and UK respectively, along with other similar programs that have been offered around the globe. If we expect hearing parents to be able to develop flexible and natural communicative interaction with their DHH infants using speech and signs then it is imperative that we establish the kinds of sign proficiency that can support effective intersubjectivity, how best to combine signs and speech and perform program evaluations that can inform the effective implantation of such language training within familial contexts.

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Figure Legends

Figure 1. The Intersubjectivity/Language Scaffolding Model of Executive Function Development. Within this model, the interaction between the development of executive functions and language development is bidirectional, but dependent upon the successful acquisition of symbolic intersubjectivity by the DHH infant. The model highlights the importance of early intervention – intersubjectivity development takes place in the first 18 months – and the role of early communicative interactions between hearing parents and their DHH infants. The model predicts that the successful development of executive function skills is likely to be heavily influenced by successful early communicative interactions, whether they be through spoken language, signed language, or – in the early stages of development – through a combination of language in both modalities.

Figures

Figure 1